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## DESCRIPTION

## METHOD FOR DESIGNING MOLD, MOLD AND MOLDED PRODUCT

## 5 Technical Field

[0001]

The present invention relates to a mold designing method for designing a mold with which a molded product in a desired shape is molded by correcting a shape change of the molded product when molding the  
10 molded product (for example, an optical lens) from the mold, a mold designed by the mold designing method, and a molded product molded by the mold.

## Background Art

15 [0002]

In molding an optical lens, when a mold is designed and produced by using designing values of the optical lens for the mold as they are, the optical lens produced with the mold sometimes is not produced in the same shape as that of the designing values. This is because of mold shrinkage being  
20 dependent on the material, stress due to the shape of the optical lens and the like, and because the mold surface of the mold is not transferred to the lens surface with high precision.

For example, when molding is performed by using a mold having a spherical molding surface to mold a spherical lens, the molded optical lens  
25 sometimes has a surface shape other than a spherical surface including an aspherical shape. Therefore, in designing a mold, it is necessary to add a

proper shape correction to the mold in consideration of these various factors.

[0003]

Correction values of the molding surfaces of these molds differ for each refractive power of optical lenses, lens material and shape of the design  
5 curved surface, and have complicated tendency by combination of them. In order to determine a suitable correction value, it is necessary to experimentally verify the actual deformation in each mold.

[0004]

Further, prediction and quantification of the correction value are  
10 difficult, and a skill is required in determination of a proper correction value.

[0005]

A concrete operation includes: (a) molding all kinds of optical lenses with the corresponding molds by tests, and (b) measuring errors with respect to the designing values of the optical lenses; (c) calculating temporary  
15 correction values (empirical values) by multiplying the measured errors by various coefficients and remake the molds; (d) molding optical lenses with the remade molds by tests again, and (e) measuring the shape errors of the optical lenses. It is a general method to repeat the above-described (c) to (e) to optimize correction.

20 [0006]

In order to perform the operation of optimizing such shape correction of a mold, however, a number of molding tests are required. Especially in the case of spectacle lenses, various kinds of molds are required. Namely, spectacle lenses, lenses corresponding to prescriptions of the individual  
25 spectacle-lenses wearers have to be prepared. For example, when the range of the refractive power at vertex of a spherical diopter is  $-8.00$  diopter (D) to

+6.00 diopter (D), and the division unit of the refractive power is 0.25D pitch, as for the diopter range of the spectacle lenses corresponding to the prescriptions, the number of kinds of spherical diopters is 56.

Further, in the case of the cylindrical refractive power corresponding  
5 to an astigmatic prescription being in the range of 0.25 diopter (D) to 2.00 diopter (D), when the division unit of refractive power is 0.25D pitch, eight kinds are required as the kind of astigmatism. Therefore, when the spherical prescription and astigmatic prescription are combined, it is necessary for a product to prepare for 448 kinds of lens diopters, and since the mold is  
10 composed of two molds that are upper and lower molds, the number of kinds of molds becomes 896 in total.

For this reason, in production of molds, the operation of shape correction for each mold as described above is performed, and therefore, a long manufacturing period is required.

15 [0007]

Meanwhile, as for a method for making correction which is added to the molding surface of a mold, there is known for a method for correcting a mold by obtaining a spherical shape having a single curvature by using the least squares method so that errors of the molded optical lens and the design  
20 values of the optical lens become the minimum, and by using the curvature of the spherical shape as an average curvature (the first prior art).

[0008]

Further, as the second prior art, there is a method for applying a predicted value as a correction value when deformation in consideration of  
25 shrinkage is predictable in the case of a simple shape (Patent Document 1).

[0009]

Further, as the third prior art, there is a method for making correction based on a shape error measurement value which is obtained by measuring a three-dimensional shape by an aspherical surface measuring machine, obtaining a shape error from the design values, and excluding a setting error with respect to the measuring machine from the shape error (Patent Document 2).

[Patent Document 1] Japanese Patent Application Laid-open No. 2003-117925

[Patent Document 2] Japanese Patent Application Laid-open No. 8-216272

#### Disclosure of the Invention

#### Problems to be solved by the Invention

[0010]

However, in the evaluation of an error by the average curvature in the first prior art, shape error other than a spherical shape cannot be evaluated, and therefore, the shape errors of the shapes other than the spherical shapes cannot be corrected.

[0011]

In the case of designing of the mold of an optical lens by using the second prior art, for example, in the case of a spectacle lens, the spectacle lens has a meniscus shape composed of a convex surface and a concave surface, and the shape is complicated; therefore, it is difficult to design the mold by predicting a transformation value with shrinkage taken into consideration.

[0012]

Further, in the third prior art, a measurement error is excluded, but the

shape error measurement value includes influence of roughness of a lens surface, foreign matters attached to the lens surface and the like as noise. Therefore, the noise other than the shape error is reflected on the correction value, and precision of correction is lowered, thus there is a possibility of being incapable of molding an optical lens from the mold with high precision.  
[0013]

In view of the above-described circumstances, an object of the present invention is to provide a mold capable of efficiently designing a mold with which a molded product in a desired shape with an aspherical curved surface is molded by correcting a shape change of the molded product when the molded product is molded from the mold, and a method for designing the mold.

Another object of the present invention is to provide a molded product by using the aforesaid mold.

Means for solving the problems  
[0014]

A method for designing a mold according to claim 1 is characterized by comprising preparing a mold of which molding surface is formed to be a design curved surface in a spherical shape of a molded product, measuring a curved surface shape of a molded product which is molded from the mold, comparing a curved surface of the above-described measured molded product and the above-described design curved surface of the above-described molded product and obtaining an error of both the curved surfaces, specifying information corresponding to the error as correction information for molding a molded product of which curved surface is in a spherical shape, and correcting a design value of the molding surface of the mold with which a

molded product with a curved surface in an aspherical shape is molded by using the above-described correction information suited to the molded product having the curved surface in the aspherical surface shape to design the molding surface.

5 [0015]

In the method for designing a mold according to claim 2 is, in the invention described in claim 1, characterized in that the above-described correction information suited to the molded product having the curved surface in the aspherical shape is correction information of a design curved surface of a molded product in a spherical shape which is of a same lens material as the molded product to be molded of which curved surface is in the aspherical shape, and has a radius of curvature that corresponds to a radius of vertex curvature on the design curved surface in the aspherical shape of the above-described molded product, or an average radius of curvature on an entire surface on the design curved surface in the aspherical shape of the molded product.

[0016]

A method for designing a mold according to claim 3 is characterized by comprising preparing a mold of which molding surface is formed to be a design curved surface in a spherical shape of a molded product, measuring a curved surface shape of a molded product which is molded from the mold, and specifying a curved surface of the above-described molded product by approximating the measured value by an equation of an aspherical surface, comparing the curved surface of the above-described molded product which is specified by the equation of the aspherical surface and the above-described design curved surface of the above-described molded product to obtain an

error of both the curved surfaces, compiling information corresponding to the error into database for each of characteristics of the molded product as correction information for molding a molded product of which curved surface is in a spherical shape, and correcting a design value of a molding surface of a mold with which a finished molded product of which curved surface is in an aspherical shape is molded by using the correction information compiled into database to design the molding surface.

[0017]

The method for designing a mold according to claim 4 is, in the invention described in claim 3, characterized in that the above-described equation of the aspherical surface is a polynomial including a spherical shape component in the curved surface of the molded product and a component other than the spherical shape in the curved surface of the molded product.

[0018]

The method for designing a mold according to claim 5 is, in the invention described in claim 3 or 4, characterized in that the above-described equation of the aspherical surface adds a spherical shape component in the curved surface of the molded product and a component other than the spherical shape in the curved surface of the molded product.

[0019]

The method for designing a mold according to claim 6 is, in the invention described in any one of claim 3 to 5, characterized in that the above-described equation of the aspherical surface is the following equation (1), where Z is a distance measured from a vertex of the molded product in an axial direction of the molded product,  $\rho$  satisfies  $\rho^2 = X^2 + Y^2$  when X and Y are distances measured in a perpendicular direction to the above-described



axis from the above-described vertex, a vertex curvature  $C$  satisfies  $C=1/R$  when  $R$  is the radius of curvature at the vertex,  $K$  is a conic coefficient, and  $A_{2i}$  is an aspherical coefficient ( $i$  is an integer).

[Mathematical Expression 1]

5

$$Z = \frac{C\rho^2}{1 + \sqrt{1 - (1 + K)C^2\rho^2}} + \sum_{i=2}^n A_{2i}\rho^{2i} \quad \text{--- (1)}$$

10 [0020]

The method for designing a mold according to claim 7 is, in the invention described in claim 6, characterized by comprising obtaining the entire shape correction information correcting the entire shape of the molding surface of the mold, which is formed to be the design curved surface in the spherical shape of the molded product, to cope with the error of the spherical shape component in the curved surface of the molded product which is molded, according to a reference spherical component which is a first term ( $K=0$ ) of the above-described equation (1), and obtaining the local shape correction information correcting a local shape of the above-described molding surface of the above-described mold, which is formed to be the design curved surface in the spherical shape of the molded product, to cope with the error of the component other than the spherical shape in the curved surface of the molded product which is molded, according to a polynomial component which is a second term of the above-described equation (1), and making each of these kinds of correction information separate and be independent and compiling it into database for each of characteristics of the

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above-described molded product of which design curved surface has the spherical shape.

[0021]

In the method for designing a mold according to claim 8 is, in the invention described in claim 7, characterized in that the above-described entire shape correction information is determined based on a difference between a radius of curvature of a reference spherical surface expressed by the reference spherical surface component which is the first term ( $K=0$ ) of the equation (1) and a radius of curvature in the design curved surface in the spherical shape of the molded product.

[0022]

The method for designing a mold according to claim 9 is, in the invention according to claim 7 or 8, characterized in that the above-described local shape correction information is determined based on a shape change rate which is expressed by the polynomial component that is the second term of the equation (1), and is calculated by using a height ( $Z$  value) of a component other than the spherical shape in the curved surface of the molded product that is molded, and a height ( $Z$  value) of the design curved surface in a spherical shape of the above-described molded product, and the above-described shape change rate is compiled into database.

[0023]

The method for designing a mold according to claim 10 is, in the invention described in any one of claims 3 to 9, characterized in that the characteristics of the above-described molded product are a lens material of the optical lens which is the molded product, and a shape of the design curved surface in the spherical shape.

[0024]

The method for designing a mold according to claim 11 is, in the invention described in any one of claims 3 to 10, characterized in that design of the molding surface of the above-described mold with which the finished  
5 molded product of which curved surface is in the aspherical shape is molded is carried out by adding the entire shape correction information and the local shape correction information, which are suited to the molded product having the curved surface in the aspherical shape and compiled into database, to the design curved surface in the aspherical shape of the molded product.

10 [0025]

The method for designing a mold according to claim 12 is, in the invention according to claim 11, characterized in that the above-described entire shape correction information and the above-described local shape correction information, which are suited to the finished molded product  
15 having the curved surface in the aspherical shape and compiled into database, are entire shape correction information and local shape correction information which are compiled into database with respect to a design curved surface of a molded product in a spherical shape, which is of a same lens material as the molded product to be molded of which curved surface is in the  
20 aspherical shape and has a radius of curvature corresponding to the average radius of curvature of the design curved surface in the aspherical shape of the above-described molded product.

[0026]

A mold according to claim 13 is characterized by being formed by  
25 carrying out the method for designing a mold according to any one of claims 1 to 12.

[0027]

The molded product according to claim 14 is characterized by being formed by using the mold described in claim 13.

[0028]

5 The molded product according to claim 15 is characterized in that the molded product described in claim 14 is a spectacle lens in a meniscus shape.

Advantageous effect of the Invention

[0029]

10 According to the invention described in claim 1 or 2, the information corresponding to the error of the curved surface of the measured molded product and the design curved surface in the spherical shape of the molded product is specified as the correction information for molding the molded product of which curved surface is in the spherical shape, and the design value of the molding surface of the mold with which the molded product  
15 having the curved surface in the aspherical shape is molded is corrected by using the above-described correction information suited to the molded product having the curved surface in the aspherical shape to design the molding surface. Therefore, by using the correction information suited to the molded product having the curved surface in the aspherical shape, the  
20 correction information correcting the design value of the molding surface of the mold with which the molded product of which curved surface is in the aspherical shape is molded can be determined in a short time. As a result, the molding surface of the mold with which the molded product in a desired shape having the aspherical curved surface can be efficiently designed.

25 [0030]

According to the invention described in any one of claims 3 to 6, and

10 to 12, the molded product is molded from the mold of which molding surface is formed to be the design curved surface in the spherical shape of the molded product, the curved surface shape of the molded product is measured, and the measured value is approximated by the equation of the aspherical surface and the curved surface of the molded product which is molded is specified as the aspherical surface. By this, of the curved surface shape of the molded product which is molded, not only the spherical component but also the components other than the spherical component can be approximated by the equation of the aspherical surface, and quantified and specified.

Therefore, the error between the curved surface of the above-described molded product specified to be the aspherical surface and the design curved surface of the spherical shape of the molded product becomes the error in which the spherical shape component and the components other than the spherical shape are accurately taken, and the correction information corresponding to the error becomes accurate.

Since the measured value of the curved shape of the molded product which is molded is approximated by the equation of the aspherical surface, and the curved surface shape of the molded product is quantified and specified as the aspherical surface, the noises such as a measurement error included in the measured value, surface roughness of the curved surface of the molded product and the like are excluded, and only the surface shape of the curved surface of the molded product which is molded can be extracted.

Further, the information corresponding to the error of the curved surface of the above-described molded product which is specified by the equation of the aspherical surface and the design curved surface in the spherical shape of the molded product is compiled into database for each of

the characteristics of the molded product as the correction information for molding the molded product of which curved surface is in the spherical shape. Then, by using the correction information compiled into database, the design value of the molding surface of the mold with which the molded product of which curved surface is in the aspherical shape is molded is corrected to design the mold. Therefore, by extracting the correction information suited to the molded product having the curved surface in the aspherical shape from the database, the correction information correcting the design value of the molding surface of the mold with which the molded product of which curved surface is in the aspherical shape is molded can be determined in a short time.

As a result of the above, the molding surface of the mold with which the molded product in a desired shape with the aspherical curved surface is molded can be efficiently designed.

[0031]

According to the invention described in any one of claims 7 to 9, the entire shape correction information correcting the entire shape of the molding surface of the mold, which is formed to be the design curved surface in the spherical shape of the molded product, is obtained to cope with the error (error of the average surface refractive power) of the spherical shape components in the curved surface of the molded product that is molded, according to the reference spherical component which is the first term ( $K=0$ ) of the equation (1). Further, the local shape correction information correcting the local shape of the above-described molding surface of the above-described mold, which is formed to be the design curved surface in the spherical shape of the molded product, is obtained to cope with the error of the components other than the spherical shape in the curved surface of the

molded product that is molded, according to the polynomial component which is the second term of the above-described equation (1). In this manner, the entire shape correction information and the local shape correction information are separately and independently obtained, whereby the error of the molded product that is molded (error of the spherical shape components and the error of the components other than the spherical shape) is reflected in the correction information with high precision, and suitable correction is carried out to be able to design the molding surface of the mold.

[0032]

According to the invention described in claims 13 to 15, even when the molded product is deformed when the molded product of which curved surface is in the aspherical shape is molded from the mold, the mold with which the molded product in a desired shape with the aspherical curved surface is molded can be efficiently designed by extracting the suited correction information from the database. Therefore, the molded product in the desired shape having the aspherical curved surface can be efficiently molded and obtained by this mold.

Best Mode for Carrying out the Invention

[0033]

Hereinafter, best modes for carrying out the present invention will be described based on the drawings.

[A] First embodiment (Fig 1 to Fig. 10)

Fig. 1 is a sectional side view showing a mold having an upper mold and a lower mold which are produced by carrying out the first embodiment in a method for designing a mold according to the present invention. Fig. 5 is a graph showing a molded curved surface, a design curved surface and the like

of an optical lens which is a molded product molded by tests from the mold in Fig. 1. Fig. 7 is a schematic diagram showing calculation or the like of entire shape correction information and local shape correction information in the design process of the upper mold and the lower mold in Fig. 1.

5 [0034]

(Explanation of Construction of Molding Mold for Producing Lens)

A mold 10 shown in Fig. 1 is for molding a plastic spherical lens by a manufacturing method called a cast method, and is constructed by including an upper mold 11, a lower mold 12 and a gasket 13. The above-described  
10 upper mold 11 and the lower mold 12 are collectively called a lens base mold.  
[0035]

The gasket 13 is formed of a resin having elasticity into a cylindrical shape, and holds the upper mold 11 and the lower mold 12 fluid-tightly at an inner peripheral surface to be spaced at a predetermined distance. A cavity  
15 14 is constructed by being enclosed by the upper mold 11, the lower mold 12 and the gasket 13. The gasket 13 is integrally provided with an injection part 15 for injecting a monomer, which is a raw material of an optical lens into the cavity 14. A height of the gasket 13 is set at such a dimension as can ensure a thickness of a peripheral edge portion of the optical lens that is a molded  
20 product.

[0036]

The upper mold 11 and the lower mold 12 are composed of glass or the like. The upper mold 11 is formed into a concave mold to form a curved surface (convex surface) of the optical lens. The lower mold 12 is formed  
25 into a convex mold to form a curved surface (concave surface) of the optical lens. In the upper mold 11 and the lower mold 12, a surface on which a lens



curved surface of the optical lens is formed is called a use surface 16 and a surface on which the above-described lens curved surface is not formed is called a nonuse surface 17 as also shown in Fig. 2.

[0037]

5 (Description of Method for Producing Optical Lens)

A manufacturing process of an optical lens using the above-described mold 10 will be described with reference to Fig. 3.

First, a monomer that is a raw material of the optical lens is prepared (S1). The monomer is a thermosetting resin, and a catalyst, an ultraviolet  
10 absorber and the like are added to the resin to be prepared, which is filtered with a filter (S2).

[0038]

Next, the upper mold 11 and the lower mold 12 is assembled to the gasket 13 to complete the mold 10 (S3). Then, the monomer prepared as  
15 described above is injected into the cavity 14 of the mold 10, and is heat-polymerized and cured in an electric furnace (S4). As the polymerization of the monomer in the mold 10 is completed, the plastic optical lens is molded, and the optical lens is released from the mold 10 (S5).

[0039]

20 After the release of the optical lens, heating treatment called anneal is carried out to remove distortion of an inside of the lens which is caused by polymerization (S6). Thereafter, visual inspection and projective inspection are carried out for the optical lens as intermediate inspection.

[0040]

25 The optical lens is classified into a finished product and a semi-finished product (semi product) at this stage, and polishing of a second

surface is performed for the semi-finished product in accordance with the prescription. For the finished product, a coloring process for obtaining a colored product, a reinforcement coating process for reinforcement against a damage, and an antireflection coating process for prevention of reflection are carried out thereafter (S7), and final inspection is carried out (S8). The finished product becomes a product after the final inspection (S9).

[0041]

A manufacturing procedure of the upper mold 11 and the lower mold 12 of the mold 10 used in the above-described manufacturing process of the optical lens will be described next with reference to Fig. 4.

The upper mold 11 and the lower mold 12 are obtained by processing both surfaces of pressed thick glass blanks, and therefore, the glass blanks are prepared first (S11).

By processing each of the glass blanks, a surface imperfection layer on a press surface of the glass blank is removed, and the use surface 16 and the nonuse surface 17 are made to have radiuses of curvature with predetermined precision and at the same time, the use surface 16 and the nonuse surface 17 with microscopic and uniform roughness with high precision are obtained. The above-described work of the glass blanks is carried out by grinding and polishing.

[0042]

In a grinding process, more specifically, a diamond wheel is used in a free curved surface grinding machine which performs an NC control, and both surfaces of the glass blanks (use surface 16 and the nonuse surface 17) are ground to predetermined radiuses of curvature (S12). By the grinding process, the upper mold 11 and the lower mold 12 are formed from the glass

blanks.

[0043]

In a polishing process, a polishing plate made by attaching polyurethane or felt onto a hollow plate of rubber is used, and with fine  
5 particle of cerium oxide/zirconium oxide or the like as an abrasive, both surfaces of the upper mold 11 and the lower mold 12 formed by grinding are polished (S13). By the polishing process, asperities on the surfaces in the use surfaces 16 and the non use surfaces 17 of the upper mold 11 and the lower mold 12, which occur in the grinding process, are removed to achieve  
10 transparency (graining removal). Then, the use surfaces 16 and the nonuse surfaces 17 are effectively finished to have sufficient surface precision.

[0044]

After the polishing process, the upper mold 11 and the lower mold 12 are inspected (S14), and a hidden mark which is a reference position of a  
15 layout pattern is marked on each of the use surfaces 16 (S15). The layout pattern indicates an optical layout of the optical lens, and is used when a circular optical lens is framed into a spectacle glass frame. The layout pattern is erasably marked on the surface of the optical lens.

[0045]

20 After marking the hidden mark, scientific glass reinforcement treatment is carried out for the upper mold 11 and the lower mold 12 (S16), and the upper mold 11 and the lower mold 12 are completed (S17). The upper mold 11 and the lower mold 12 are produced in accordance with the refractive power of the prescription of the optical lens, and therefore, many  
25 kinds of the upper molds 11 and the lower molds 12 as well as the gaskets 13 are required.

[0046]

(Description of Method for Designing Mold)

A designing procedure of the upper mold 11 and the lower mold 12 in the mold 10, which are produced as described above, will be described next  
5 with reference to Fig. 5 and Fig. 7.

First, the mold 10 with which the optical lens being a molded product is molded by tests is prepared. The above-described optical lens to be molded is a spherical lens of which curved surface is a spherical curved surface. Accordingly, the use surfaces 16 which are the molding surfaces in  
10 the upper mold 11 and the lower mold 12 of the mold 10 are also formed into spherical shapes. In this case, a radius of curvature of the use surface 16 of each of the upper mold 11 and the lower mold 12 is formed to be equal to a set value of the curved surface of the optical lens (for example, a design radius of curvature  $R_0$  at the vertex as a radius of curvature at the vertex  
15 power of the lens). Note that the curved surface of the optical lens having the design radius of curvature  $R_0$  at the vertex is called a design curved surface 20 (Fig. 5).

[0047]

Next, a molding test is carried out by using the mold 10 including the  
20 above-described upper mold 11 and the lower mold 12, a monomer is injected into the mold 10 and is heat-polymerized, and thereby, the optical lens which is a test molded product is molded. The curved surface shape of the optical lens molded by tests is not formed into a spherical shape due to thermal shrinkage of the monomer, and the like. The inventor of the present  
25 invention has found out that the major constituent of an error due to shape change after molding can be approximated by the equation of the aspherical

surface expressed by the following expression (1) as a result of the earnest study. Namely, the curved surface shape of the optical lens formed by tests is molded into the shape other than a spherical shape, which includes an aspherical shape. Thus, the curved surface shape of the surface of the optical lens thus molded is measured by using the shape measuring machine with a later-described transfer marking 32 (Fig. 9) as a reference (S21 in Fig. 7). Then, the measured value is approximated by the equation of the aspherical surface by using the least square method, and the curved surface of the optical lens molded by tests is quantified and specified as an aspherical surface.

[0048]

The above-described equation of the aspherical surface is the following equation (1) expressing the aspherical shape of rotational symmetry, where Z is a distance measured from a vertex O in the direction of an optical axis P,  $\rho$  satisfies  $\rho^2 = X^2 + Y^2$  when X and Y are distances measured from the above-described vertex O in a direction perpendicular to the above-described optical axis P, a vertex curvature C satisfies  $C = 1/R$  when R is the radius of curvature at the vertex, K is a conic coefficient, and  $A_{2i}$  is an aspherical coefficient (i is an integer). The equation (1) is also called the equation of Spencer. (for details, see J. Opt. Soc. Am 52(1962)672)

[Mathematical Expression 2]

$$Z = \frac{C\rho^2}{1 + \sqrt{1 - (1 + K)C^2\rho^2}} + \sum_{i=2}^n A_{2i}\rho^{2i} \quad \text{—————} \quad (1)$$

[0049]

However, in reality, in order to facilitate the calculation, by using the following equation (2) which is the result of transforming the above-described equation (1), the above-described measured value is approximated by the equation (2) by using the least square method, and quantified and specified, and a coefficient  $B_{2i}$  (coefficient including the vertex curvature  $C$  and the aspherical coefficient  $A_{2i}$  of the equation (1)) of the equation (2) is calculated. Here,  $i$  of the coefficient  $B_{2i}$  is an integer.

[Mathematical Expression 3]

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$$Z = \sum_{i=1}^n B_{2i} \rho^{2i} \quad \text{————— (2)}$$

[0050]

Transformation from the equation (1) to the equation (2) is performed as follows. Namely, when the first term of the equation (1) is rationalized with  $Q=1+K$  ( $K$  is a conic coefficient),

[Mathematical Expression 4]

$$\text{FIRST TERM OF THE EQUATION (1)} = \frac{1 - \sqrt{1 - QC^2 \rho^2}}{QC} \quad \text{————— (a)}$$

When the part of the square root is series-expanded,

[Mathematical Expression 5]

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$$\sqrt{1 - QC^2 \rho^2} = 1 - \frac{QC^2 \rho^2}{2} - \frac{Q^2 C^4 \rho^4}{8} - \frac{Q^3 C^6 \rho^6}{16} - \frac{5Q^4 C^8 \rho^8}{128} - \frac{7Q^5 C^{10} \rho^{10}}{256} - \dots$$

When this is substituted into the equation (a),

[Mathematical expression 6]

$$\begin{array}{l} 5 \quad \text{FIRST TERM OF} \\ \text{THE EQUATION (1)} \end{array} = \frac{C\rho^2}{2} + \frac{QC^3\rho^4}{8} + \frac{Q^2C^5\rho^6}{16} + \frac{5Q^3C^7\rho^8}{128} + \frac{7Q^4C^9\rho^{10}}{256} + \dots$$

When this is substituted into the equation (1) and is arranged as the polynomial equation of  $\rho$ , the above-described equation (1) can be expressed by the following equation (2).

10 [Mathematical Expression 7]

$$\begin{aligned} Z &= \left(\frac{C}{2}\right)\rho^2 + \left(\frac{QC^3}{8} + A_4\right)\rho^4 + \left(\frac{Q^2C^5}{16} + A_6\right)\rho^6 + \left(\frac{5Q^3C^7}{128} + A_8\right)\rho^8 + \dots \\ &= \sum_{i=1}^{\infty} B_{2i}\rho^{2i} \end{aligned} \quad \text{————— (2)}$$

15

Note that

[Mathematical Expression 8]

$$\begin{array}{l} 20 \quad B_2 = \left(\frac{C}{2}\right), \quad B_4 = \left(\frac{QC^3}{8} + A_4\right), \quad B_6 = \left(\frac{Q^2C^5}{16} + A_6\right), \\ \quad B_8 = \left(\frac{5Q^3C^7}{128} + A_8\right), \dots \text{————— (b)} \end{array}$$

[0051]

25 As described above, from the coefficient  $B_{2i}$  which is calculated by approximating the measured value of the curved surface shape of the optical lens molded by tests by the equation (2), the vertex curvature  $C$  and the

aspherical coefficient  $A_{2i}$  of the equation (1) are calculated by using the above-described equation (b). Thereby, the curved surface shape of the optical lens molded by tests is quantified by the equation (1) and specified. However, the measurement value of the curved surface shape of the optical lens molded by tests may be directly approximated by the equation (1) and quantified to be specified, and the vertex curvature  $C$  and the aspherical coefficient  $A_{2i}$  of the equation (1) may be obtained. In each case, on quantification by the equation (1), the conic coefficient  $K$  is set at  $K=0$  (namely,  $Q=1$ ), and the vertex curvature  $C$  is calculated with the first term of the equation (1) used as the equation which expresses the spherical surface, then the aspherical coefficients  $A_4$ ,  $A_6$ ,  $A_8$  and  $A_{10}$  are calculated with  $i=2, 3, 4$  and  $5$ .

[0052]

The curved surface shape of the optical lens molded by tests, which is specified by the equation (1) is shown as a molded curved surface 21 in Fig. 5. The molded curved surface 21 is in the aspherical shape. Reference numeral 22 in Fig. 5 shows a curved surface shape of a reference spherical component which is the first term ( $K=0$ ) of the equation (1) of the molded curved surface 21 of the optical lens, which is quantified and specified by the equation (1). The curved surface shape 22 shows the spherical surface (reference spherical surface) with the radius of curvature  $R$  at the vertex ( $R=1/C$ ) which is the inverse number of the vertex curvature  $C$  of the equation (1) as the radius of curvature.

[0053]

Further, ZN in Fig. 5 represents a component other than the spherical shape of the molded curved surface 21 of the optical lens quantified and



specified by the equation (1), and shows the polynomial component that is the second term of the equation (1). The above-described polynomial component represented by the ZN is an error component with respect to the reference spherical component of the first term of the equation (1) as expressed by reference numeral 23 in Fig. 6.

[0054]

Next, data of the optical lens which is molded by tests and quantified and specified by the equation (1) is analyzed (S22 in Fig. 7). In this data analysis, the vertex curvature C (radius of curvature R at the vertex) of the equation (1) and the aspherical coefficients  $A_4$ ,  $A_6$ ,  $A_8$  and  $A_{10}$  are used. For example, when the design radius of curvature  $R_0$  at the vertex of the design curved surface 20 of the optical lens is set at  $R_0=532.680$  mm, the radius of curvature R at the vertex ( $=1/C$ ) of the molded curved surface 21 of the optical lens which is molded from the mold 10 having the upper mold 11 and the lower mold 12 each with the use surface 16 formed to be the above-described design curved surface 20, and is quantified and specified by the equation (1) is set at  $R=489.001$  mm, and the aspherical coefficients  $A_4$ ,  $A_6$ ,  $A_8$  and  $A_{10}$  are set as shown in Table 1. The radius of curvature R at the vertex and the aspherical coefficients  $A_4$ ,  $A_6$ ,  $A_8$  and  $A_{10}$  are used in the data analysis.

[Table 1]

i	ASPHERICAL COEFFICIENT	ASPHERICAL COEFFICIENT VALUE
2	$A_4$	$1.35749160310267 \times 10^{-7}$
3	$A_6$	$-5.09568302053733 \times 10^{-11}$
4	$A_8$	$-3.82812002603438 \times 10^{-15}$
5	$A_{10}$	$3.9996422621367 \times 10^{-18}$

[0055]

(Mold Designing Method: Separation of Spherical and Aspherical Components of Error)

5 In this data analysis, the reference spherical component which is the first term of the equation (1) by which the optical lens molded by tests is quantified and specified, and the polynomial component which is the second term of the equation (1) are dealt separately and independently.

10 Incidentally, in the prior art, the spherical component and the aspherical component of a shape error are integrally corrected. Accordingly, as for the correction coefficient of the shape error, the same coefficient is applied to the spherical component and the aspherical component. However, the correction numeric value of each lens shape which will be described later totally differs for each shape in the spherical component and the aspherical component of a shape error. For example, Fig. 12(b) shows a correction  
15 numeric value on the concave surface side of the spherical component of the shape error. Fig. 12(b) shows that even if the surface shape of the lens changes, the spherical component correction value on the concave surface side is constant except for some shapes. Further, Fig. 12(a) shows the correction numeric value on the convex surface side of the spherical  
20 component of the shape error. The correction numeric value shown in Fig. 12(a) indicates that the shape of the convex side becomes constant at the refractive power of 4D or more. Namely, as for the entire shape correction value, the correction numeric values of the shape errors are constant on both concave and convex surfaces at the refractive power of 4D or more. Namely,  
25 as for the entire shape correction value, the correction numeric values of the shape errors are constant on both the concave and convex surfaces at the

refractive power of 4D or more. On the other hand, the aspherical component of the shape error shows a different value at each refractive power, and there is no tendency in the shape error and the correction value, and the shape of the molded product.

5           However, in the prior art, the spherical component and the aspherical component of a shape error are integrally corrected. Accordingly, the correction values are changed in all the shapes. However, correction is made by changing the correction values for the shape error spherical components of the lens shape at the refractive power of 4D or more for which the correction  
10   value does not have to be changed originally, and therefore, determination of the correction values is further complicated. As a result, suitable correction values are determined by sufficiently repeating trial manufacture for each of all the molds. In this embodiment, the spherical component and the aspherical component of a shape error are separated, and correction  
15   information is obtained independently, whereby proper correction is carried out and the mold can be easily designed.

[0056]

          Namely, information, which corresponds to an error of the spherical component among errors between the molded curved surface 21 (Fig. 5) of  
20   the optical lens molded by tests and quantified and specified by the equation (1) and the design curved surface 20 of the optical lens, is calculated by using the reference spherical component (shape expressed by the curved surface shape 22 in Fig. 5) that is the first term ( $K=0$ ) of the equation (1). The information is set as entire shape correction information (S23 in Fig. 7). The  
25   entire shape correction information is for correcting the entire surface shape of the use surfaces 16 in the upper mold 11 and the lower mold 12 of the

mold 10 and by eliminating the error of the above-described spherical shape component.

[0057]

5 More specifically, a difference  $H$  in a  $Z$ -direction between the radius of curvature  $R$  at the vertex of the curved shape 22 (reference spherical surface) expressed by the reference spherical component that is the first term ( $K=0$ ) of the equation (1) which quantifies and specifies the molded optical lens, and the design radius of curvature  $R_0$  at the vertex in the design curved surface 20 of the optical lens is calculated as an error of the spherical shape component in the molded curved surface 21 of the molded optical lens. The difference  $H$  is determined as the entire shape correction information. The entire shape correction information is necessary correction information for the molded optical lens to obtain desired refractive power.

[0058]

15 The radius of curvature  $R$  at the vertex of the curved surface shape 22 (reference spherical surface) expressed by the reference spherical component that is the first term ( $K=0$ ) of the equation (1) which quantifies and specifies the molded optical lens, and the design radius of curvature  $R_0$  at the vertex in the design curved surface 20 of the optical lens sometimes do not correspond with each other due to the rate of shrinkage of a raw material. The rate of shrinkage differs in each raw material. When the difference between the radius of curvature  $R$  at the vertex and the design radius of curvature  $R_0$  at the vertex is  $2D$  or less, preferably  $1D$  or less, in surface refraction power conversion of a later-described equation (3), the molded curved surface of the molded product (optical lens) can be formed into a desired shape by using the above-described entire shape correction information and the later-described

20

25

local shape correction information.

[0059]

Further, information, which corresponds to an error of the components other than the spherical shape among errors between the molded  
5 curved surface 21 of the optical lens molded by tests and quantified and specified by the equation (1) and the design curved surface 20 of the optical lens, is calculated by using the polynomial component (expressed by ZN in Fig. 5) which is the second term of the equation (1). The information is set as the local shape correction information. (S24 in Fig. 7). The local shape  
10 correction information is for correcting the local shape of the use surfaces 16 in the upper mold 11 and the lower mold 12 of the mold 10, namely, partially correcting the use surfaces 16 and eliminating errors of the components other than the above-described spherical shape.

[0060]

15 More specifically, a shape change rate is calculated by using a height (Z value) ZN of the component other than the spherical shape in the molded curved surface 21 (Fig. 5) of the optical lens, which is expressed by the polynomial component that is the second term of the equation (1) quantifying and specifying the molded optical lens, and a height (Z value) ZM in the  
20 design curved surface 20 of the optical lens. The shape change rate is calculated with the shape change rate =  $ZN/ZM$ , and is calculated at each position from the vertex of the optical lens molded by tests. The local shape correction information is calculated and determined in each position from the vertex of the optical lens molded by tests as the value obtained by  
25 multiplying the shape change rate in the position by the height ZM of the design curved surface 20 of the optical lens at the position.

[0061]

Here, the above-described height  $Z_N$  is expressed by the difference of the respective heights ( $Z$  values) at the same position from the vertex of the optical lens in the curved surface shape 22 (reference spherical surface) expressed by the reference spherical component of the first term ( $K=0$ ) of the equation (1) and the molded curved surface 21 of the optical lens molded and specified by the equation (1).

[0062]

Finally, the use surfaces 16 of the upper mold 11 and the lower mold 12 in the mold 10 are corrected and designed by using the local shape correction information and the entire shape correction information calculated as described above (S25 in Fig. 7).

[0063]

Namely, the local shape correction information corresponding to each position is first added in the  $Z$ -direction to the design value of each position from the vertex of the lens in the use surfaces 16 of the upper mold 11 and the lower mold 12 formed to be the design curved surface 20 of the optical lens. Thereby, the errors of the components other than the spherical shape in the molded curved surface 21 of the optical lens to be molded are eliminated. Next, the entire shape correction information (difference  $H$ ) is added in the  $Z$ -direction to the design values of the entire surfaces in the use surfaces 16 of the upper mold 11 and the lower mold 12 to which the local shape correction information is added. Thereby, the errors of the spherical components in the molded curved surface 21 of the optical lens to be molded are eliminated. In this manner, the design values of the use surfaces 16 of the upper mold 11 and the lower mold 12 are corrected, and the use surfaces 16 are designed.

[0064]

Addition of the above-described entire shape correction information may be carried out only for the design value of the use surface 16 of the lower mold 12. The reason is that the lower mold 12 is common in various kinds of optical lenses, and has less the number of use surfaces 16 to be corrected than the upper mold 11 does. Besides, the reason is that the influence is considered to uniformly act on the curved surface (convex surface) of the optical lens by changing the radius of curvature of the curved surface (concave surface) of the optical lens molded by the use surface 16 of the lower mold 12.

[0065]

A design procedure for correcting and designing the use surfaces 16 of the upper mold 11 and the lower mold 12 as described above will be further described with reference to Fig. 8.

The use surfaces 16 of the upper mold 11 and the lower mold 12 have to be larger than the size of the optical lens to be molded, and therefore, the design values of the use surfaces 16 are calculated by increasing the design values of the curved surfaces of the optical lens (S31). Based on the calculated design values, the upper mold 11 and the lower mold 12 are produced so that the use surfaces 16 become equal to the design curved surfaces of the optical lens (design radius of curvature  $R_0$  at the vertex), and the mold 10 is assembled (S32).

[0066]

Next, a monomer is injected into the assembled mold 10, the optical lens is molded by tests, and the curved surface shape of the optical lens being the molded product is measured by using a shape measuring device with a

later-described transfer marking 32 (Fig. 9) as a reference (S33). As the shape measuring device, for example, Form Talysurf made by Taylor Hobson Ltd. is mainly used in this embodiment, but a non-contact type three-dimensional measuring device (for example, UA3P made by Matsushita Electric Industrial Co., Ltd., and the like) and the like can be used, and the measuring device is not especially limited. In Form Talysurf, ruby or diamond is set at a tip end of a probe, the tip end of the probe moves on the surface of a lens in contact with the surface and scans the lens surface to measure the surface shape, and its measuring locus is usually only a straight line. Meanwhile, the three-dimensional measuring device is a type of scanning surfaces with floating from a measured surface by a very small constant amount due to an intermolecular force.

[0067]

Next, the above-described measurement value of the optical lens molded by tests is approximated by using the least square method in the equation (2), then the curved surface shape of the molded optical lens is quantified and specified, and the coefficient  $B_{2i}$  is calculated. Further, from the coefficient  $B_{2i}$ , by using the equation (b), the vertex curvature  $C$  of the equation (1) ( $K=0$ ) and the aspheric coefficients  $A_4$ ,  $A_6$ ,  $A_8$  and  $A_{10}$  are calculated, and the curved surface shape of the molded optical lens is quantified and specified by the equation (1) ( $K=0$ ).

Thereafter, by using the above-described vertex curvature  $C$  and aspherical coefficients  $A_4$ ,  $A_6$ ,  $A_8$  and  $A_{10}$ , data of the optical lens molded and quantified by the equation (1) is analyzed (S34). In this case, the first term ( $K=0$ ) and the second term of the equation (1) are treated separately and independently, the entire shape correction information is calculated from the



first term ( $K=0$ ) (S35), and the local shape correction information is calculated from the second term. (S36).

[0068]

Next, the calculated local shape correction information and entire shape correction information are added to the design values of the respective use surfaces 16 of the upper mold 11 and the lower mold 12 which are formed to be the design curved surface (design radius of curvature  $R_0$  at the vertex) of the optical lens, and the use surfaces 16 are corrected and designed (S37).

10 [0069]

Next, design of the nonuse surfaces 17 of the upper mold 11 and the lower mold 12 is carried out (S38). Then, data for a processing machine is created from the design values of the use surfaces 16 and the nonuse surfaces 17 in the upper mold 11 and the lower mold 12 (S39). Thereafter, glass blanks are selected, and the upper mold 11 and the lower mold 12 of the mold 10 are produced by a grinding machine and a polishing machine (S40).

[0070]

(Comparison of Molded Product Precision of Embodiment and Prior Art)

20 The shape precision of the molded product according to this embodiment will be described.

The optical lens molded by the mold 10 having the upper mold 11 and the lower mold 12 which are produced as described above has the curved surfaces in desired spherical shapes. For example, Fig. 10(A) is a shape error measurement result when the curved surface of the molded product according to this embodiment is measured in the different diameter directions (two

orthogonal directions to each other in the drawing). Fig. 10(B) is a shape error measurement result when the curved surface of the molded product according to the above-described first prior art is measured in the different diameter directions (two orthogonal directions to each other in the drawing).  
5 Fig. 10A and Fig. 10B are the measurement results of the molded products which are optical lenses with the surface refraction power of 5.00 D (diopter) molded by the mold 10. In Fig. 10, the horizontal axis represents a distance (mm) from a lens center (vertex), and 0 at the central part of the graph represents an optical lens center. The vertical axis represents a refractive  
10 power error amount, and 0.00 D indicates no error. Based on Fig. 10, shape error amounts of the molded products molded according to this embodiment and the first prior art will be described in detail.

[0071]

A lens central part will be explained first. The lens central part is  
15 frequently used and is especially important as the optical center. The error amounts at the optical lens central parts obviously differ, and the error amount is 0.06 D in this embodiment (Fig. 10(A)) while in the first prior art (Fig. 10(B)), the error amount is 0.18 D. Accordingly, it turns out that the precision is enhanced by three times in this embodiment as compared with  
20 the above-described prior art.

Further, a peripheral part other than the lens central part will be explained. In this peripheral part, the shape error with respect to the design curved surface of the optical lens when the curved surface of the molded optical lens is measured in the different diameter directions (two directions  
25 orthogonal to each other in the drawing) is small in the molded product according to this embodiment in any position of each part of the lens. When

comparing the shape errors in the vicinity of the outer diameter of 50 mm of the spectacle lens used in a general spectacle frame, the error amount is about 0.02 D in this embodiment, while in the first prior art, the error amount is 0.04 D. Accordingly, it is found out that, precision in this embodiment is  
 5 enhanced about twice as high as the one in the above-described prior art.

Further, as for the error amount of this embodiment, the change amount of the error is small and gentle from the lens central part to the peripheral part as compared with the first prior art. Therefore, there is the effect of having less incompatibility even if the visual line position moves  
 10 from the central part to the peripheral part by rotation of an eye.

From these results, it is determined that the optical lens molded in the mold 10 according to the designing method of this embodiment is in the substantially equal shape to the design curved surface. Besides, it is found out that the optical lens molded by the mold in the first prior art is in the  
 15 shape different from the design curved surface.

[0072]

Here, each of the vertical axes in Figs. 10(A) and 10(B) represents the refractive power error (unit: D (diopter)). The refractive power error is the error of the radius of curvature  $r$  (unit: m) indicating the curved shape of the  
 20 optical lens, which is converted into the error of the surface refractive power  $P$  (unit: D (diopter)) of the above-described curved surface of the optical lens by the following equation (3).

$$P = (n-1) / r \quad \dots(3)$$

In this equation (3),  $n$  represents a refractive index of the optical lens. Note  
 25 that in the optical lens in the meniscus shape having the convex surface and the concave surface, the sum of the surface refractive powers of the convex

surface and the concave surface expresses the refractive power of the optical lens.

[0073]

(Explanation of Surface Shape Measurement)

5       Next, the transfer mark 32 (Fig. 9(A)) set as a reference when the curved shape of the optical lens molded by tests in step 21 in Fig. 7 and step 33 in Fig. 8 will be described. The transfer mark 32 is formed by transferring marks (not shown) formed on the use surfaces 16 of the upper mold 11 and the lower mold 12 of the mold onto the curved surface 31 of the optical lens  
10   30 which is molded by tests.

[0074]

      Further, as is understood from the Figs. 9(B) and 9(C), the transfer mark 32 has a vertex transfer mark part 33 which is formed on the portion of the vertex O in the curved surface 31 of the optical lens 30, and a pair of  
15   peripheral edge part transfer mark parts 34A and 34B formed at positions which are on the peripheral edge part of the above-described curved surface 31 and symmetrical with respect to the above-described vertex O. Further, the above-described vertex transfer mark part 33 has a main vertex transfer mark part 35 which is formed at the vertex O of the curved surface 31, and  
20   sub vertex transfer mark parts 36 which radiate out at predetermined distances from the main vertex transfer mark part 35 and are formed to be orthogonal to each other.

[0075]

      For example, the main vertex transfer mark part 35 is a circular  
25   convex part with the diameter of about 0.5 mm. Further, the peripheral edge part transfer mark parts 34A and 34B are circular convex parts each with a

diameter of about 1 mm. Further, the sub vertex transfer mark part 36 is a rectangular convex part with the length S of about 2 mm, a spaced distance T between the sub vertex transfer mark parts 36 on the same straight line of about 1 mm, and width dimension of the sub vertex transfer mark part 36 of several tens  $\mu\text{m}$ .

[0076]

On each of the use surfaces 16 of the upper mold 11 and the lower mold 12, markings (not shown) in concave shapes in the corresponding sizes are formed at the positions corresponding to the above-described main vertex transfer mark part 35, the sub vertex transfer mark parts 36, and the peripheral edge part transfer mark parts 34A and 34B. Thereby, the above-described vertex transfer mark 33 (the main vertex transfer mark part 35, the sub vertex transfer mark parts 36), the peripheral part transfer mark parts 34A and 34B are transferred and formed on the curved surface 31 of the optical lens 30. The markings for transferring the peripheral part transfer mark parts 34A and 34B are cut to be about 1 mm in diameter and several  $\mu\text{m}$  in depth. The marking for transferring the main vertex transfer mark part 35 is cut to be about 0.5 mm in diameter and about 0.5  $\mu\text{m}$  or less in depth. The marking for transferring the sub vertex transfer mark part 36 is formed by being scribed to be several tens  $\mu\text{m}$  in width and several  $\mu\text{m}$  or less in depth.

[0077]

The vertex transfer mark part 33 (especially the main vertex transfer mark part 35), and the peripheral edge part transfer mark parts 34A and 34B, which are transferred to be formed on the curved surface 31 of the optical lens 30, are on the same straight line L1 passing the vertex O of the curved surface 31. The shape measuring device which measures the shape of the

curved surface 31 of the optical lens 30 measures the shape of the above-described curved surface 31 by sequentially passing the peripheral part transfer mark part 34A, the vertex transfer mark part 33 and the peripheral part transfer mark part 34B along the above-described straight line L1, and thereby the shape measuring device is capable of accurately measuring the shape of the curved surface 31. Accordingly, the vertex transfer mark part 33 (especially, the main vertex transfer mark part 35), and the peripheral edge part transfer mark parts 34A and 34B are located at the spot where the curved surface 31 of the optical lens 30 should be measured.

10 [0078]

When the shape measuring device measures the curved surface 31 of the optical lens 30 by sequentially passing the peripheral edge part transfer mark part 34A, the vertex transfer mark part 33 and the peripheral edge part transfer mark part 34B along the straight line L1, the vertex transfer mark part 33, the peripheral edge part transfer mark parts 34A and 34B have an extreme shape change, and therefore, it is measured as a large noise. Therefore, when the noise of the vertex transfer mark part 33, the peripheral edge part transfer mark parts 34A and 34B is not measured, it is obvious that the shape measurement in the curved surface 31 of the optical lens 30 by the shape measuring device is not accurately carried out. In this case, setting of the optical lens 30 with respect to the shape measuring device is adjusted, so that the shape measuring device performs measurement by sequentially passing the peripheral edge part transfer mark part 34A, the vertex transfer mark part 33 and the peripheral edge part transfer mark part 34B.

25 [0079]

Note that the large noise in the above-described measured value

caused by the vertex transfer mark part 33, and the peripheral edge part transfer mark parts 34A and 34B can be easily excluded without having an influence on the measured values nearby. Thereafter, the above-described measured value is approximated by the equation (1) of the aspherical surface or the equation (2) by using the least square method as described above, and therefore, no influence is on the measured value. As for the measurement error of the vertex transfer mark part 33, and the peripheral edge part transfer mark parts 34A and 34B, the measurement error for the peripheral edge part transfer mark parts 34A and 34B is within about 0.5 mm because the peripheral edge part transfer mark parts 34A and 34B are each in a circular shape of about 1 mm in diameter. The measurement error for the main vertex transfer mark part 35 is within about 0.25 mm because the main vertex transfer mark part 35 of the vertex transfer mark part 33 is in a circular shape of about 0.5 mm in diameter.

[0080]

The present invention is not limited to the case where a set of peripheral edge transfer mark parts 34A and 34B are provided to be symmetric with respect to the vertex O in the curved surface 31 of the optical lens 30, but a plurality of peripheral edge transfer mark parts 34A and 34B may be provided. For example, another set of peripheral edge part transfer mark parts 34A and 34B may be transferred on a straight line L2, which is rotated at a predetermined angle (for example, 90 degrees) with respect to the straight line L1 including the peripheral edge part transfer mark parts 34A and 34B as well as the peripheral part transfer mark parts 34A and 34B on the straight line L1. The shape measuring device measures the curved surface 31 of the optical lens 30 in the different diameter directions along the above-

described straight lines L1 and L2, and thereby, it becomes possible to accurately measure the curved surface 31 of the optical lens 30 such as a toric lens, for example, in both the orthogonal axial directions.

[0081]

5           The transfer mark 32 is further provided in an optional direction in the curved surface 31 of the optical lens 30, and in this direction, the curved surface shape of the curved surface 31 may be measured in this direction by the shape measuring device.

[0082]

10           (Effect of the First Embodiment)

Since the first embodiment is constructed as above, the following effects (1) to (5) are provided according to the above-described embodiment.

(1) The curved surface shape of the optical lens which is molded from the mold 10 including the upper mold 11 and the lower mold 12 is measured, and the measured value is approximated by the equation (1) that is the equation of the aspherical surface and the curved surface of the optical lens is specified as the aspherical surface. Therefore, of the curved surface shape of the molded optical lens, not only the spherical components but also the components other than the spherical components can be approximated by the equation (1) of the aspherical surface, and quantified and specified. Accordingly, the error between the curved surface of the optical lens specified to be the aspherical surface and the design curved surface of the optical lens becomes the error in which the spherical shape components and the components of the shape other than the spherical shape are accurately taken. As a result, the correction information corresponding to the above-described error becomes accurate, the upper mold 11 and the lower mold 12



can be designed by precisely correcting the use surfaces 16 of the upper mold 11 and the lower mold 12 in the mold 10.

[0083]

(2) The measured value of the curved surface shape of the molded optical lens is approximated by the equation (1) which is the equation of the aspherical surface, and the curved shape of the above-described optical lens is quantified and specified as the aspherical surface. Accordingly, the measurement error included in the measured value and a noise such as surface roughness of the curved surface of the optical lens can be excluded, and only the measured value of the curved surface of the optical lens can be extracted. Therefore, the upper mold 11 and the lower mold 12 can be designed by precisely carrying out the correction of the use surfaces 16 of the upper mold 11 and the lower mold 12 in the mold 10.

[0084]

(3) Based on the reference spherical component which is the first term ( $K=0$ ) of the equation (1), the entire shape correction information for correcting the entire shapes of the use surfaces 16 of the upper mold 11 and the lower mold 12 in the mold 10 is obtained to cope with the error (error of the average surface refractive power) of the spherical shape component in the curved surface of the molded optical lens. Based on the polynomial component which is the second term of the above-described equation (1), the local shape correction information for correcting the local shapes of the use surfaces 16 of the above-described upper mold 11 and the lower mold 12 is obtained to cope with the error of the components other than the spherical shape in the curved surface of the molded optical lens. By obtaining the entire shape correction information and the local shape correction

information separately and independently in this manner, the upper mold 11 and the lower mold 12 can be designed by precisely reflecting the errors of the optical lens (the error of the spherical shape component and the error of the components other than the spherical shape) in the correction information and carrying out suitable correction.

[0085]

(4) The measured value obtained by measuring the curved shape of the molded optical lens is approximated by the equation (2) which is the equation of the aspherical surface and the curved surface of the above-described optical lens is specified. Therefore, as compared with the case where the curved surface of the optical lens is specified by using the equation (1) which is difficult to handle with a calculator, determination can be carried out by easy calculation, and the coefficient  $B_{2i}$  of the equation (2) can be quickly calculated. Therefore, the correction information corresponding to the deformation (error) of the optical lens is easily calculated, and the upper mold 11 and the lower mold 12 of the mold 10 for molding the optical lens in a desired shape can be easily designed.

[0086]

(5) The marks (not shown) provided at the use surfaces 16 in the upper mold 11 and the lower mold 12 of the mold 10 are transferred onto the curved surface 31 of the optical lens 30 shown in Fig. 9 and the transfer mark 32 (vertex transfer mark part 33, the peripheral part transfer mark parts 34A and 34B) is formed thereon. The transfer mark 32 is located at the spot which should be measured in the curved surface 31 of the optical lens 30. When the curved shape of the optical lens formed from the mold 10 is measured, the shape of the curved surface 31 of the above-described optical

lens 30 is measured as the above-described transfer marking 32 located at the spot to be measured as a reference. Thereby, measurement of the curved surface shape of the optical lens 30 can be accurately carried out. As a result, the measured value is approximated by the equation (1) or the equation (2) of the aspherical surface, the curved surface of the optical lens is specified as the aspherical surface, the correction information is calculated, and thereby, the use surfaces 16 of the upper mold 11 and the lower mold 12 in the mold 10 can be precisely designed.

[0087]

10 [B] Second Embodiment (Fig. 11, Fig. 12)

(Explanation of Compiling Correction Information into Database)

Fig. 11 is a graph showing a shape change rate curve which is a part of the local shape correction information compiled into database that is used in a second embodiment in the method for designing a mold according to the present invention. Fig. 12 is a graph showing the entire shape correction information which is compiled into database that is used in the second embodiment in the method for designing the mold according to the present invention. In the second embodiment, the explanation of the same parts as in the aforementioned first embodiment will be omitted by using the same reference numerals and symbols, and the names.

20 [0088]

The second embodiment differs from the aforementioned first embodiment in the following point. In Fig. 8, steps S31 to S40 are previously carried out for all kinds of molds. On this occasion, each correction information is compiled into database. After creation of the database, steps S35 to S40 are carried out without performing steps S31 to S34.

Namely, in the first embodiment, one kind of optical lens is molded by tests concerning the lens material and the design curved surface shape of the optical lens, and the correction information (the entire shape correction information, the local shape correction information) is obtained. By directly  
5 using the correction information, the upper mold 11 and the lower mold 12 of the mold 10 are corrected and designed.

On the other hand, in the second embodiment, a number of kinds of optical lens differing in the lens material and the design curved surface shape of the optical lens as the characteristics of the optical lens are respectively  
10 molded by tests in advance, and the correction information obtained at that time is compiled into database for each characteristic of the optical lens. After creation of the database, the design values of the use surfaces 16 of the upper mold 11 and the lower mold 12 of the mold 10 for mass production of each of the optical lenses are corrected and designed by using the correction  
15 information compiled into database without another test-molding or by only simple test molding.

[0089]

Namely, in the second embodiment, the use surfaces 16 of the upper molds 11 and the lower molds 12 of a large number of molds 10 with which  
20 molds respective plurality of kinds of optical lenses differing in the shape of the design curved surface are molded are designed with respect to each of a number of lens materials with different refractive indexes. The optical lenses are molded by tests by using a large number of designed molds 10, and the curved surface shape is measured for each of the molded optical lenses. Then,  
25 as in the aforementioned embodiment, the above-described measured value is approximated by the equation (2) and the curved surface shape of each of the

optical lenses is quantified. At this time, the vertex curvature  $C$  and the aspherical coefficient  $A_{2i}$  (aspherical coefficients  $A_4, A_6, A_8, A_{10}$ ) are obtained from the calculated coefficient  $B_{2i}$ , and the curved surface shape of each of the molded optical lenses is quantified and specified by the equation (1).

[0090]

Then, as in the aforementioned embodiment, data analysis is performed with respect to each of the curved surface shape of the optical lenses which are molded and specified by the equation (1). Then, the entire shape correction information is obtained from the first term ( $K=0$ ) of the equation (1) of each of them; and the shape change rate curve which is a part of the local shape correction information is obtained from the second term of the equation (1) of each of them.

[0091]

Fig. 11 shows the shape change rate curve of each molded optical lens in each position from the lens vertex in the optical lens when a plurality of optical lenses differing in the shape of the design curved surface are molded. In this case, the refractive index of the lens material of the optical lens is 1.699. In Fig. 11, the horizontal axis represents a distance (mm) from the lens center, and 0 at the central portion of the graph represents the optical lens center. The vertical axis in Fig. 11 represents the shape change rate, and 0% indicates no shape change and no need of correction.

As shown as an example in Fig. 11, the shape change rate curve of the molded optical lens is calculated for each lens material differing in refractive index and each shape of the design curved surfaces of the optical lenses, and is compiled into database. Reference symbols a, b, c, d and e in Fig. 11

represent the shape change rate curves when the shapes (radiuses of curvature) of the design curved surfaces of the optical lenses are respectively the shape corresponding to +2.00 D, the shape corresponding to 0.00 D, the shape corresponding to -2.00 D, the shape corresponding to -6.00 D, and the shape corresponding to -10.00 D.

[0092]

In Fig. 12, the horizontal axis represents the surface refractive power (D) expressing the lens shape, and numeric value 1 on the horizontal axis represents the lens shape with a large radius of curvature and a small curve value, while numeral value 6 on the horizontal axis represents the lens shape with a small radius of curvature and a large curve value. The vertical axis represents the entire shape correction value, and 0 D indicates no shape change and no need of correction.

Fig. 12 shows relationships of the entire shape correction information of molded optical lenses and the design curved surfaces of the optical lenses by the curve  $\alpha$  on the convex surface side and by a curve  $\beta$  on the concave surface side respectively when a plurality of optical lenses differing in the shape of the design curved surface of the optical lens are molded. In this case, the optical lens has the lens material of a refractive index of 1.699, and is a spectacle glass lens in the meniscus shape having the convex surface and the concave surface. As shown as an example in Fig. 12, the entire shape correction information of the molded optical lens is calculated for each lens material differing in refractive index, and for each shape of the design curved surface of the optical lens, and is compiled into database.

[0093]

Note that in Fig. 11 and Fig. 12, the shapes (radius of curvatures) of

the design curved surfaces of the optical lenses are shown by being converted into surface refractive power (unit: D (diopter)) by using the aforementioned equation (3).

[0094]

5           The case of producing the optical lenses in volume with different lens materials and different shapes of the design curved surfaces will be described. First, among the shape change rate curves of the optical lenses compiled into database as described above, the shape change rate curve concerning the optical lens with the same lens material (the same refractive index) and the same design curved surface shape as the optical lens to be produced in  
10 volume is extracted. Then, the value of an optional position from the lens vertex of the shape change rate curve is multiplied by the height (Z value) of the design curved surface of the optical lens in the corresponding position to calculate the local shape correction information in the position. The local  
15 shape correction information is calculated in all the positions of the optical lens. More specifically, when the refractive index is 1.669, and the curved surface shape corresponds to  $-6.00$  D, the shape change curve d in Fig. 11 is selected. Then, by multiplying the corresponding lens design surface height (Z value), the local correction information is determined in all the positions  
20 in the optical lens. Similarly, when the curved surface shape corresponds to  $-10.00$  D, the shape change rate curve e in Fig. 11 is selected.

Incidentally, Fig. 11 shows that if the curved surface shape changes even with the same lens material, the shape change rate curve changes dynamically. Further, the curved surface shape value  $-2.00$  D (curve c in Fig.  
25 11) is smaller in shape change rate than the curved surface shape value  $-6.00$  D (curve d in Fig. 11), and the shape change rate and the curve value of the

curvature shape are proportional to each other. However, the curved surface shape value  $-10.00$  D (curve e in Fig. 11) is smaller in shape change rate than the curved surface shape value  $-2.00$  D (curve c in Fig. 11), and they are inversely proportional to each other. Accordingly, it turns out that the shape change of the complicated shape as a lens expresses a complicated form and it is difficult to perform proper correction with the prior art.

[0095]

Next, the entire shape correction information concerning the optical lens of the same lens material (the same refractive index) and the same design curved shape as the optical lens to be produced in volume is extracted from the entire shape correction information of the optical lens which is compiled into database.

Incidentally, Fig. 12 shows that when the curved shape changes even with the same lens material, the entire shape correction value also changes irregularly. For example, in the convex surface, the entire shape correction value is proportional to the surface refractive power at the surface refractive power of 0 to 3D. On the other hand, when the surface refractive power becomes larger than 4D, the entire shape correction value becomes constant at  $-0.05$  D. Further, on the concave surface side, the entire shape correction value is constant except at some surface refractive powers. Accordingly, it is determined that the shape change of the complicated shape as a lens is unpredictable at present and it is difficult to perform suitable correction with the prior art.

[0096]

The use surfaces 16 in the upper mold 11 and the lower mold 12 of the mold 10 are designed to be the design curved surfaces of the optical lens



to be produced in volume. When the optical lens is produced in volume, the local shape correction information calculated based on the shape change rate curve which is extracted from the database as described above and the entire shape correction information extracted from the database are added  
5 respectively to the design values of the above-described use surfaces 16 in the Z-direction. Thereby, the design values of the use surfaces 16 in the upper mold 11 and the lower mold 12 of the mold 10 for molding the optical lens to be produced in volume are corrected and calculated, and the upper mold 11 and the lower mold 12 of the mold 10 are designed.

10 [0097]

(Effect of the Second Embodiment)

As constructed as above, the above-described second embodiment also provides the following effect (6) other than the same effects as the effects (1) to (5) in the aforementioned first embodiment.

15 (6) The entire shape correction information and the shape change rate curve which is a part of the local shape correction information are made to separate and be independent, and are compiled into database for each lens material and each shape of the design curved surface of the optical lens, and by using each correction information compiled into database and the like, the  
20 design values of the use surfaces 16 in the upper mold 11 and the lower mold 12 of the mold 10 are corrected and designed. As a result of this, by taking out the entire shape correction information and the local shape correction information (to be accurate, the shape change rate curve which is a part of the local shape correction information) which are suitable for the lens material  
25 and the shape of the design curved surface of the optical lens from the database, correction information and the like of the design values of the use

surfaces 16 in the upper mold 11 and the lower mold 12 of the mold 10 can be determined in a short time without carrying out test molding. As a result, the use surfaces 16 in the upper mold 11 and the lower mold 12 of the mold 10 can be efficiently designed.

5 [0098]

[C] Third Embodiment

(Explanation of Aspherical Shape Correcting Method by Spherical Correction Value)

10 The third embodiment is for correcting and designing design values of the use surfaces which are molding surfaces in the upper mold and the lower mold of the mold with which a molded product (optical lens) with the curved surface in the aspherical shape is molded by utilizing the correction information (the entire shape correction information, the shape change rate which is a part of the local shape correction information) which is compiled  
15 into database in the aforementioned second embodiment and for molding a molded product (optical lens) with the curved surface in a spherical shape.

[0099]

20 The method for compiling the entire shape correction information for molding the optical lens with the curved surface in a spherical shape, and the shape change rate which is a part of the local shape correction information into database for each characteristic of the optical lens with the design curved surface having a spherical shape is the same as the aforesaid second embodiment, and the explanation of the method will be omitted. Here, the characteristics of the above-described optical lens are the lens material of the  
25 optical lens with the curved surface in the spherical shape, and the shape of the design curved surface having the spherical shape.

[0100]

Design of the use surfaces in the upper mold and the lower mold of the mold for molding the optical lens with the curved surface in an aspherical shape starts first with extraction of the entire shape correction information and the shape change rate which is a part of the local shape correction information which are compiled into database and suitable for the optical lens having the aspherical shape.

[0101]

Namely, the entire shape correction information and the shape change rate that is a part of the local shape correction information, which are compiled into database, about the optical lens which is of the same lens material as the optical lens with the curved surface in the aspherical shape to be molded and includes the design curved surface of the spherical shape having the radius of curvature corresponding to the radius of curvature at the vertex or the average radius of curvature in the design curved surface of the aspherical shape of the optical lens are extracted from the database. Here, the above-described radius of curvature at the vertex means, for example, the radius of vertex curvature in the design curved surface of the aspherical shape of the optical lens to be molded. The above-described average radius of curvature means the average radius of curvature in the entire surface of the lens in the design curved surface of the aspherical shape of the optical lens to be molded.

[0102]

(Aspherical Shape Correcting Method by Spherical Correction Value:  
Correction Value Calculation from Database)

For example, the case where the radius of curvature at the vertex of

the design curved surface of the optical lens with the curved surface to be molded is in an aspherical shape is +2.00 D (diopter) is considered. First, with respect to the optical lens which is of the same lens material as the optical lens to be molded and including the design curved surface of the spherical shape having the radius of curvature corresponding to the above-described radius of curvature at the vertex, the corresponding database is referred to. On the convex surface side, at 2 D of "refractive power expressing the convex surface side lens shape" on the horizontal axis, the corresponding entire shape correction value of  $-0.100$  D on the curve  $\alpha$  is taken out as the entire shape correction information from the entire shape correction information shown in, for example, Fig. 12. Meanwhile, on the concave surface side, at 2 D of "refractive power expressing the concave surface side lens shape" on the horizontal axis, the corresponding entire shape correction value of  $-0.125$  D on the curve  $\beta$  is extracted. Similarly, from the shape change rate which is a part of the local shape correction information shown in, for example, Fig. 11 compiled into database, the curve  $a$  is taken out as the shape change rate.

[0103]

Next, the value at an optional position from the lens vertex at the extracted shape change rate is multiplied by the height ( $Z$  value) of the design curved surface of the aspherical shape of the optical lens at the corresponding position, and thereby, the local shape correction information at the position is calculated. Then, the local shape correction information is calculated at all the positions of the optical lens with the curved surface in the aspherical shape.

[0104]

(Aspherical Shape Correcting Method by Spherical Surface Correction Value: Method for Adding Correction Value)

Next, the local shape correction information calculated based on the shape change rate extracted from the database as described above, and the entire shape correction information extracted from the database are added in the Z-direction to the design values of the use surfaces in the upper mold and the lower mold of the mold, which are designed to be the design curved surface of the aspherical shape of the optical lens to be molded.

[0105]

As for the local shape correction information, for example, the local shape correction information calculated at each position of the optical lens of which curved surface is in the aspherical shape is added in the Z-direction to the design value at each position in the use surfaces of the above-described upper mold and lower mold designed to be the design curved surface of the aspherical shape. As for the entire shape correction information, the entire shape correction information extracted from the database is added in the Z-direction to, for example, the design values at the vertexes in the use surfaces of the above-described upper mold and lower mold, which are designed to be the design values of the aspherical shape.

[0106]

As described above, the design values of the use surfaces in the upper mold and the lower mold of the mold for molding the optical lens of which curved surfaces are in the aspherical shape are corrected and calculated, and the upper mold and the lower mold of the mold are designed.

[0107]

(Effect of the Third Embodiment)

Since it is constructed as above, the above-described third embodiment provides the following effect (7) in addition to the effects (1) to (5) of the aforesaid first embodiment.

[0108]

5           (7) Information corresponding to an error of the curved surface of the above-described optical lens specified by the equation of the aspherical surface and the design curved surface of the spherical shape of the optical lens is compiled into database for each characteristic of the optical lens as the correction information for molding the optical lens of which curved surface  
10 are in spherical shape. Then, by using the correction information compiled into the database, the design values of the use surfaces in the upper mold and the lower mold of the mold for molding the optical lens of which curved surfaces are in the aspherical shapes are corrected and designed. As a result of this, by extracting the correction information suitable for the optical lens  
15 having the curved surfaces in the aspherical shapes from the database, the correction information for correcting the design values of the use surfaces in the upper mold and the lower mold of the mold for molding the optical lens of which curved surfaces are in the aspherical shapes can be determined in a short time. As a result, the use surfaces in the upper mold and the lower mold  
20 of the mold for molding the optical lens in a desired shape, of which curved surfaces are aspherical surfaces can be efficiently designed.

Industrial Availability

[0109]

25           The present invention is described based on the above-described each embodiment thus far, but the present invention is not limited to this.

For example, in the embodiments, the optical lens is manufactured by

being molded by using the cast method, but the present invention can be also applied to the case where the optical lens is manufactured according to the manufacturing method other than the cast method. In concrete, in the case where the plastic lens is directly cut and polished, the present invention can  
5 be applied to cut surface shape data correction in a grinding process, the shape correction and the refractive power correction of the polishing tool (polishing plate) in a polishing process. Further, the present invention is applicable to correction or the like of a slumping mold.

[0110]

10 Besides, the case where the mold is glass is described in the above-described embodiments, but the present invention can be applied to other molds with a high thermal shrinkage factor, for example, in the case of molding by a metal mold.

[0111]

15 In the above-described embodiments, the case where the optical lens of which surface is in a spherical shape is described as the test molded product. However, an optical lens of which surface is in an aspherical shape can be applied as the test molded product.

[0112]

20 Further, in the above-described embodiment, the case of the optical lens of which surface is in a spherical shape and is rotationally symmetrical, or the optical lens of which surface is in an aspherical shape is described as a finished molded product, but the optical lenses having a toric surface, an atoric surface and the like can be made as finished molded products. Here,  
25 the toric surface means the surface which has two principal meridians orthogonal to each other, with each principal meridians constructed by a

spherical shape. The atoric surface means the surface with each of its principal meridians constructed by an aspherical shape.

[0113]

In the above-described embodiment, the method in which the curved surface shape of the surface of the optical lens that is the molded product is measured on one meridian (namely, diameter) passing the center of the optical lens and data analysis is performed is described, but the method in which the curved surface shape is measured on a plurality of meridians (namely, diameter) passing the center of the optical lens, data analysis is performed and the average value of them is calculated may be adopted.

Brief Description of Drawings

[0114]

Fig. 1 is a sectional side view showing a mold having an upper mold and a lower mold which are produced by carrying out a first embodiment in a method for designing a mold according to the present invention;

Fig. 2 is a sectional side view showing the lower mold in Fig. 1;

Fig. 3 is a flowchart showing a production procedure of an optical lens (plastic lens) using the mold in Fig. 1;

Fig. 4 is a flowchart showing a production procedure of the upper mold and the lower mold in Fig. 1;

Fig. 5 is a graph showing a molded curved surface 21, a design curved surface 20 and the like of the optical lens which is a molded product molded by tests from the mold in Fig. 1;

Fig. 6 is a graph showing a deviation amount by which a polynomial component of the molded curved surface 21 of the optical lens, which is molded by tests and specified by the equation (1), deviates with respect to the



reference spherical surface component (curved surface shape 22) in Fig. 5;

Fig. 7 is a schematic diagram showing calculation and the like of entire shape correction information and local shape correction information in a design process of the upper mold and the lower mold in Fig. 1;

5 Fig. 8 is a flowchart concretely showing a design procedure of the upper mold and the lower mold in Fig. 1;

Fig. 9(A) is a front view showing a transfer marking which is transferred from the mold in Fig. 1 and formed on a curved surface of the optical lens, Fig. 9(B) is a partially enlarged view showing a vertex transfer marking of Fig. 9(A), and Fig. 9(C) is a partially enlarged view showing a peripheral edge part transfer marking in Fig. 9(A);

Fig. 10 shows a shape error which the molded curved surface of the optical lens that is the molded product has with respect to the design curved surface at each position of the optical lens, Fig. 10(A) is a graph in the case of the optical lens molded by using the mold designed by the method for designing the mold in the first embodiment, and Fig. 10(B) is a graph in the case of the optical lens molded by the mold which is designed by making correction by using an average curvature in a first prior art;

Fig. 11 is a graph showing a shape change rate that is a part of the local shape correction information compiled into database, which is used in a second embodiment in the method for designing a mold according to the present invention; and

Fig. 12 is a graph showing the entire shape correction information that is compiled into database, which is used in the second embodiment in the method for designing the mold according to the present invention.

25 Explanation for references

[0115]

- 10 A mold
- 11 A upper mold
- 12 A lower mold
- 5 16 use surfaces (a molded surface)
- 20 A designed curved surface
- 21 A molded curved surface
- 22, 23 A curved shape
- 30 An optical lens
- 10 31 A curved surface
- 32 A transfer mark
- 33 A vertex transfer mark part
- 34A, 34B peripheral part transfer mark parts
- $A_{2i}$  A aspherical coefficient
- 15  $B_{2i}$  A coefficient
- C A vertex curvature
- $R_0$  A design radius of curvature at the vertex
- R A radius of curvature at the vertex
- O A vertex
- 20 P An optical axis